Original Research Article

The usefulness of multivariate analysis in forestry research: A case study of Wild Pomegranate (*Punica granatum* L)

Abstract: The present study deals with the Contrast, Cluster, Discriminant and Principal Component Analysis. The data for the present study was collected. Data on different morphological and seedling characters, namely Tree height (m), Tree diameter (cm), Crown spread E-W (m), Crown spread N-S (m), Fruit weight (g), Leaf length(cm), Internodal length(cm), Collar diameter (mm), Number of branches per plant and leaf petiole (cm) were considered from five different districts comprising of ten seed sources. Two seed sources were considered from each district *viz*; Narag and Neripul from Sirmour district, Waknaghat and Sadhupul from Solan district, Sundernagar and Rewalsar from Mandi district, Mohal and Banjar from Kullu district, Basantpur and Sunni from Shimla district. Different morphological and seedling characteristics of ten seed sources were evaluated by contrast analysis, which varied significantly among the different districts and within the districts. It is concluded that Tree diameter (cm), Crown spread E-W (m) and Crown spread N-S (m)was found Maximum in Solan district and Minimum in Shimla district, whereas Collar diameter (mm), Leaf length (cm) and Number of branches per plant was found Maximum in Mandi district and Minimum in Shimla district. Tree height (m) and Leaf petiole was recorded maximum in Kullu and Sirmour district and minimum in Shimla district whereas Fruit weight (g) and internodal length (cm) was found Maximum in Mandi district and minimum in Solan and Sirmour district.Cluster analysis was performed and the seed sources were grouped into three clusters. Discriminant analysis was carried out to categorize the seed sources into high and low yielders. Tree diameter, Tree height and Crown spread E-W are the most important characters that discriminate the two groups. Six seed sources from Mandi, Kullu and Shimla district were high yielder whereas other four seed sources were low yielder. Three principal components (PC_S) were extracted out of ten which explained 34.675, 23.002, and 11.587 per cent of the total variation respectively amounting to 69.26 per cent of total variation.

Key words: *Principal component analysis, Cluster analysis, Discriminant analysis, Punica granatum L, Wild Pomegranate*

Introduction: Wild pomegranate (*Punica granatum* L.) is commonly known as daru, dalim or dadima. It is one of the oldest known edible fruit crops. It is believed to be originated in South West Asia, probably in Iran and some adjoining countries (De Candolle, 1967). Pomegranate probably originated in Iran (Simmonds 1976; Levin 1994) and from there it is diversified to other regions like Mediterranean countries, China, Pakistan and Afghanistan, possibly through ancient trade routes. It is one of the oldest known edible fruits (Damania 2005). Pomegranate (*Punica* granatum L., Punicaceae) has been cultivated in Iran since ancient times and wild pomegranate still grow in parts of Iran (Goor and Libeman 1956; Levin 1994). It is a deciduous agro-forestry as well as Horticulture cash crop. It belongs to family Punicaceae. It grows as shrub or small tree and is often armed. It is found throughout the Mediterranean region. In India, it is found in vast tract of hill slopes of Himachal Pradesh, Jammu & Kashmir and Uttarakhand at an altitude of 900 to 1800 m amsl. In Himachal Pradesh, it is distributed in some pockets of Solan, Sirmour, Mandi, Shimla, Kullu and Chamba districts (Bhrot, 1998). The most important center of wild pomegranate in Himachal Pradesh is Darlaghat, which is about 40 km from Shimla.

Wild pomegranate grows well on slightly hot climate characterized by dry summer and prolonged winter. This species provides a good source of income for villagers and farmers. Seeds with aril is sun dried and commercially marketed as Anardana. Anardana is a good source of Sugar, Vitamin C, and iron. Ref??? The powdered flower buds are used in Bronchitis. Fruit rind, juice of leaves, and young fruits are used for the treatment of Gastrointestinal disorders. The fruit rind, root, stem bark, and leaves are good sources of Tannin, It is one of the esteemed dessert fruit and is very much liked by people for its cool refreshing juice, and taste and is highly valued for its nutritional and medicinal properties. The pomegranate and its usage and deeply embedded in human history, and utilization is found in many ancient human cultures as food and as a medical remedy. Despite this fact, pomegranate culture has been restricted to generally consider a minor crop. The pomegranate tree requires a long, hot, and dry season to produce a good yield of high-quality fruit.

The yield of the tree may get affected by many growth characteristics, but researchers are always interested to identify those sets of characters (parameters) that significantly affect the yield of the tree. Keeping in view the economic importance of this species present study was conducted to discriminate high-yielder and low-yielder seed sources and to assess the relative contribution of different morphological and seedling characteristics.

Materials and Methods: Data on different morphological and seedling characters were considered from five different districts.

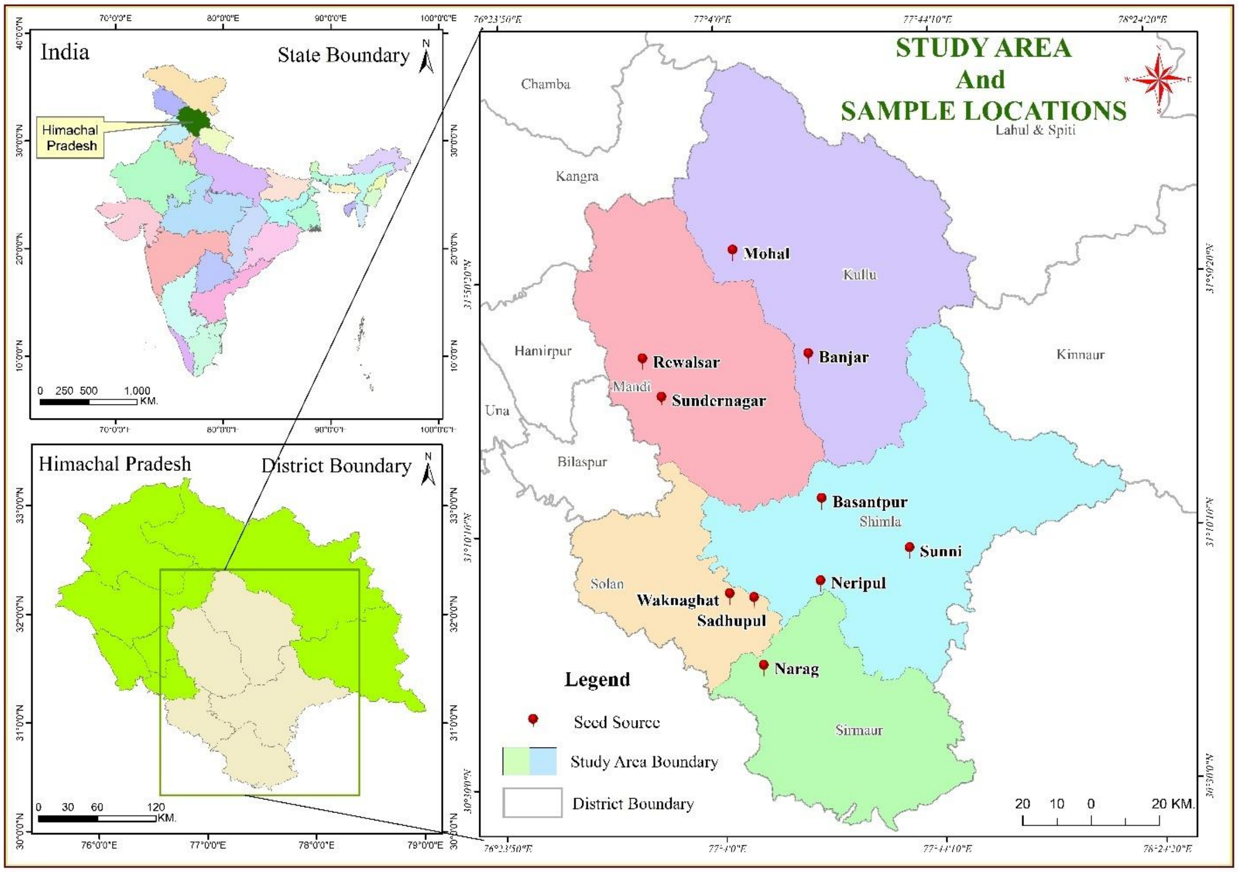

Fig:1: Study Area and Sample Locations (Source: Arc GIS Software)

Table 1: Seed sources selected randomly from five different districts:

Name of District	Number of Seed Sources	Name of Seed Sources
Shimla	2	Basantpur, Sunni
Sirmour	2	Narag, Neripul
Solan	2	Waknaghat, Sadhupul
Kullu	2	Mohal, Banjar
Mandi	2	Rewalsar, Sundernagar

The data on various morphological characteristics were collected from each seed source for the present study *viz.* Tree height (m), Tree diameter (cm), Crown spread E-W (m), Crown spread N-S (m), Fruit weight (g), Leaf length (cm), Internodal length (cm), also Nursery was raised and data on characteristics *i.e* Collar diameter (mm), Number of branches per plant and Leaf petiole (cm) were recorded.

Different morphological and Seedling characteristics of ten seed sources were evaluated by Contrast Analysis. Different multivariate tools like Discriminant Analysis, Cluster Analysis, and Principle component Analysis were used to gather information about the concerned objective.

ANALYTICAL FRAMEWORK

In order to test mean differences between district and within districts, ANOVA technique by using contrast analysis has been used for each characteristic.

i) Number of districts : 5

ii) Number of seed sources from each district : 2

iii) Total number of seed sources : 10

iv) Replication : 3

v) Design : Randomized Block Design (RBD)

1) Contrast Analysis: Contrast analysis was used to test the significant differences of the seed sources among the districts and within district for all the characters under study (Table1a). Performance of various characteristics among different districts and within districts were compared by using contrast analysis.

Table 1a Analysis of variance among districts and within districts

Source of variation	d.f.	Sum of square	MSS	F calculated	F table
Replication	2	RSS	$\frac{RSS}{2}$ =MSR	$\frac{MSR}{MSE}$	$F_{0.05}$ (2,18)
Seed sources	9	tSS	$\frac{tSS}{9}$=MSt	$\frac{MST}{MSE}$	$F_{0.05}$ (9,18)
Between district	4	BSS	$\frac{BSS}{4}$=MSB	$\frac{MSB}{MSE}$	$F_{0.05}$ (4,18)
Seed source within district Shimla	1	WSS_1	$\frac{WSS_1}{1}$=$MSWS_1$	$\frac{MSWS_1}{MSE}$	$F_{0.05}$ (1,18)
Seed source within district Sirmour	1	WSS_2	$\frac{WSS_2}{1}$=$MSWS_2$	$\frac{MSWS_2}{MSE}$	$F_{0.05}$ (1,18)
Seed source within district Solan	1	WSS_3	$\frac{WSS_3}{1}$=$MSWS_3$	$\frac{MSWS_3}{MSE}$	$F_{0.05}$ (1,18)
Seed source within district Kullu	1	WSS_4	$\frac{WSS_4}{1}$=$MSWS_4$	$\frac{MSWS_4}{MSE}$	$F_{0.05}$ (1,18)
Seed source within district Mandi	1	WSS_5	$\frac{WSS_5}{1}$=$MSWS_5$	$\frac{MSWS_5}{MSE}$	$F_{0.05}$ (1,18)
Error	18	ESS	$\frac{ESS}{18}$=MSE		
Total	29	TSS			

$CD_{0.05}$ Between districts: $t_{(0.05,\,18)} \times \sqrt{\frac{2 \times MSE}{2r}}$

$CD_{0.05}$ Seed sources within districts: $t_{(0.05, 18)} \times \sqrt{\frac{2 \times MSE}{r}}$

Where RSS =Replication Sum of Square

tSS = Seed Sources Sum of Square

TSS=Total Sum of Square of Seed Sources

BSS=Sum of Square between district

WSS_1=Sum of Square of Seed Sources within district Shimla

WSS_2=Sum of Square of Seed Sources within district Sirmour

WSS_3=Sum of Square of Seed Sources within district Solan

WSS_4=Sum of Square of Seed Sources within district Kullu

WSS_5=Sum of Square ofSeed Sources within district Mandi

$MSWS_1$=Mean Sum of Square of Seed Sources within district Shimla

$MSWS_2$=Mean Sum of Square of Seed Sources within district Sirmour

$MSWS_3$=Mean Sum of Square of Seed Sources within district Solan

$MSWS_4$=Mean Sum of Square of Seed Sources within district Kullu

$MSWS_5$=Mean Sum of Square of Seed Sources within district Mandi

Cluster Analysis: Sometimes a situation arises when certain multivariate populations are found to be heterogeneous and there is need to find out which subsets of populations are most alike and which are least alike. The cluster analysis was done by Mahalanobis D^2 statistic as suggested by Rao (1952). It included following steps:

i) A set of uncorrelated linear combination (y's) was obtained by pivotal condensation of the common dispersion matrix Rao (1952) of the set of correlated variable (x's).

ii) Using the relationship between y's and x's the mean value of different seed sources for different characters (x_1 to x_{10}) were transformed into the mean values of an uncorrelated linear combination (y_1 to y_{10}).

iii) Treating D^2 as the generalized statistical distance between a pair of populations, all populations were grouped into number of clusters according to method described by Rao (1952). The criteria used in clustering by this method was that any two seed sources belonging to same cluster, at least on an average, show a small D^2 value (inter cluster distance) than those belonging to two different clusters. In other words, if seed sources T_1 and T_2 are close together then these two will grouped in same cluster.

Discriminant analysis: Fisher (1936) introduced discriminant function analysis. With the help of this technique a set of multiple measurement were used to provide a discriminant function (linear) in the observation and having the property that, better than any other linear functions. Thus, the problem is reduced to that of single variable by choosing a linear component of the original variables and by constructing a statistic suitable for univariate case. The maximized value of this statistic obtained by a suitable choice of coefficients is taken as the appropriate test criteria. Under these circumstances the method of discriminant analysis frequently obtains more satisfactory result than a regression or correlation analysis.

Let d_1, d_2,....,d_p are the 'p' normal variate with same dispersion matrix (α_{ij}) but distributed independently of W_{ij}, where W_{ij} (i j =1,2,........,p) is the matrix giving the estimates on n degrees of freedom of the elements in the dispersion matrix (α_{ij}) of p-normally correlated variables. Considering only the first r variables, d_1, d_2, …,d_r the statistic T_r is defined by:

$$nT_r = \sum_{i=1}^{p} \sum_{j=1}^{p} W_r^{ij}\, d_i d_j$$

Where W_r^{ij} is the matrix reciprocal to W_{ij} (i, j =1,2,........,r)

such that, $\frac{n-r+1}{r} T_r \sim F\,(r, n-r+1)$

It can be easily shown that if d_{r+1},.......,$d_p$are distributed independently of d_1, d_2,.......d_r and $E(d_{r+i})$ = ... $E(d_p)$ =0, $E(d_i)$ being not necessarily zero when i = 1,2....r, the statistic is distributed as:

$$\frac{n-p+1}{p-r} U_{p-r,\, r} \sim F\ (p\text{-}r,\ n\text{-}p\text{+}1)$$

The average value of W for class I and II having number of cases a and b respectively was given by:

$$\bar{W}_I^a = \lambda_1 \bar{X}_1^a + \lambda_2 \bar{X}_2^a + \ldots + \lambda_p \bar{X}_p^a$$

$$\begin{matrix} . & & . \\ . & & . \\ . & & . \end{matrix}$$

$$\bar{W}_{II}^a = \lambda_1 \bar{X}_I^b + \lambda_2 \bar{X}_2^b + \ldots + \lambda_p \bar{X}_p^b$$

The cut-off point choosing between class I and II lies between $\bar{W}_I^a$and $\bar{W}_{II}^a$. Its exact valuecould be dependent on the relative cost of miss-classifying the units, but frequently it is taken as the midpoint between W_I and W_{II}.A test of the hypothesis that the discriminant function has no discriminating provided **by**the F- test constructed as follows:

$$F = \left[\frac{\frac{n_I n_{II}/(n_I+n_{II}) D^2}{p}}{\frac{D}{n-p-1}} \right] \text{with p and n-p-1 df}$$

where D =$\bar{W}_1^a$ and $\bar{W}_{II}^a$= $\sum \lambda_j d_j$ and n= $n_I + n_{II}$

The real adequacy of the discriminant function, however, must be determined by how well it discriminates between classes I and II on a fresh sample of data. Ten seed sources of *Punica granatum*L.were divided into high and low yielder groups.

Principal Component Analysis: It is a multivariate statistical technique to reduce the data with large number of correlated variables in to a substantially smaller set of new variables. A principal component analysis is concerned with explaining the variance - covariance structure of a set of variables through a few linear combinations of these variables. Its general objectives are:

1. Data reduction
2. Interpretation

It does not require the assumption of multivariate normality. It deals with the internal structure of the variables involved. Its aim is to sacrifice some information contained in the original variables in order to keep as few variables as possible, but the lost information is kept as minimum as possible.

Biology, economics, meteorology, anthropology, social sciences and agriculture are some of the areas where the technique of principal component analysis is widely used. It has been used in conjunction with discriminant analysis for improving the stability of the coefficients, multiple regression analysis to tackle the problem of multicollinearity.

The aim of principal component analysis is to ascertain new variables, called principal components, which carry most of the information present in original variables. Principal Components are generally estimated from either the correlation matrix (R) or sample variance-covariance matrix (S). When the variables are measured in different units, scale effect can influence the composition of the derived components. In order to overcome such situation it is desirable to standardize the variable. Also, correlation matrix should be used.

The first few principal components usually account for most of the variation of the original variables and the variation described by following principal components is relatively little, it is often useful to retain only those first few principal components and drop all subsequent components from the analysis. It is so because the variable they express is largely random and is of no use in the analysis. Several thumb rules have been proposed for the number of principal components of the correlation matrix with eigen roots less than one. The principal component's with the variance less than one contains less information.

Various steps involved in worked out of principal components can be summarized as below:

i) First of all, Keyser – meyer – olkin measure for sampling adequacy is computed. If the value of KMO comes out to be more than 0.5 only then we should go for principal component analysis.

ii) After that find the eigen value of variance-covariance matrix or correlation matrix.

iii) Arrange eigen values in decreasing order. Let these values in decreasing order be λ_1, λ_2,. . ., λ_p and corresponding variability be V_1, V_2 …. V_p, where $V_p$is variability for $\lambda_{p.}$

iv) Starting from first principal component, go on adding the variance of first few principal components whose value is more than unity. The variability described by them is of greater use. Discard the remaining principal components.

v) From the eigen vectors of chosen principal components variables which load therespective principal components are found.

The output desired for interpretation and grouping should include:

i) Eigen value and percentage of total variation explained by each principal component.

ii) The eigen vector for each principal component.

iii) The principal component scores.

iv) The correlation between original Standardized variable and the corresponding principal component scores (occasionally called loading).

Principal component analysis technique was used to identify the important characteristics contributing towards the yield of *Punica granatum* L.

Results:

Contrast Analysis: Different morphological and seedling characteristics of ten seed sources were evaluated by contrast analysis, which varied significantly among districts and within the districts. It is concluded that Tree Diameter (cm), crown spread E-W (m), and crown spread N-S (m) were found maximum in the Solan district and minimum in the Shimla district, whereas collar diameter (mm), leaf length (cm) and a number of branches per plant was found maximum in mandi district and minimum in Shimla district. Tree height (m) and leaf petiole was recorded as maximum in Kullu and Sirmour district and minimum in the Shimla district whereas fruit weight (g) and internodal length (cm) was found maximum in the mandi district and minimum in Solan and Sirmour district.

Table 1b: Mean variation of height (m) of *Punica granatum* among districts and within districts

Seed sources	**Seed source 1**	**Seed source 2**	**Mean**
Shimla	3.96	4.76	4.36
Sirmour	5.46	6.37	5.92
Solan	7.41	8.35	7.88
Kullu	7.90	8.17	8.04

Mandi	7.83	7.30	7.57
$CD_{0.05}$	**District**	0.03	
	Seed sources within district	0.05	

Table 1b: showed that the height was recorded maximum (8.04 m) in district Kullu which was significantly higher from rest of the districts whereas minimum (4.36 m) height was recorded in Shimla district. Within districts maximum height of (8.35 m) was recorded in seed source 2 of district Solan and minimum height of (3.96) was recorded in seed source 1 of Shimla district which was significantly different from rest of the seed sources within districts.

Table1c: Mean variation of tree diameter (cm) of *Punica granatum* L. among districts and within district

Seed sources	**Seed source 1**	**Seed source 2**	**Mean**
Shimla	9.43	10.40	9.91
Sirmour	11.79	12.84	12.31
Solan	13.79	14.72	14.26
Kullu	13.86	12.97	13.41
Mandi	12.07	11.30	11.68
$CD_{0.05}$	**District**	0.30	
	Seed sources within district	0.42	

Table 1c showed that thetree diameter was recorded maximum (14.26 cm) in district Solan, whereas minimum (9.91 cm) tree diameter was recorded in Shimla district. Within districts among both the seed sources maximum tree diameter of (14.72 cm) was recorded in seed source 2 of district Solan and minimum tree diameter of (9.43 cm) was recorded in seed source 1 of Shimla district which was significantly different with rest of the seed sources within districts.

Table1d: Mean variation of crown spread E-W (m) of *Punica granatum* L.among districts and within district

Seed sources	Seed source 1	Seed source 2	Mean
Shimla	3.40	3.65	3.52
Sirmour	4.07	4.66	4.37
Solan	4.96	5.12	5.04
Kullu	4.81	4.76	4.79
Mandi	4.37	4.11	4.24
$CD_{0.05}$	**District**	0.03	
	Seed sources within district	0.05	

Table 1d showed that the crown spread E-W was recorded maximum (5.04 m) in district Solan which was significantly higher from rest of the districts, whereas minimum (3.52 m) crown spread E-W was recorded in Shimla district. Within districts maximum crown spread E-W of (5.12 m) was recorded in seed source 2 of district Solan and minimum crown spread E-W of (3.40 m) was recorded in seed source 1 of Shimla district.

Table1e: Mean variation of crown spread N-S (m) of *Punica granatum* L.among districts and within district

Seed sources	Seed source 1	Seed source 2	Mean
Shimla	5.44	5.69	5.56
Sirmour	6.14	6.55	6.35
Solan	6.75	6.74	6.74
Kullu	6.55	6.41	6.48
Mandi	6.09	5.93	6.01
$CD_{0.05}$	**District**	0.21	
	Seed sources within district	0.29	

Table 1e showed that thecrown spread N-S was recorded maximum (6.74 m) in district Solan which was significantly higher as compared to rest of the districts, whereas minimum (5.56 m) crown spread N-S was recorded in Shimla district. Within districts among both the seed sources maximum crown spread N-S of (6.75 m) was recorded in seed source 1 of district Solan and minimum crown spread N-S of (5.44 m) was recorded in seed source 1 of Shimla district which was significantly different with rest of the seed sources within districts.

Table1f: Mean variation of leaf length (cm) of *Punica granatum* L.among districts and within district

Seed sources	**Seed source 1**	**Seed source 2**	**Mean**
Shimla	3.80	4.60	3.93
Sirmour	4.26	4.50	4.38
Solan	4.69	4.99	4.84
Kullu	5.09	5.24	5.17
Mandi	5.31	5.30	5.30
$CD_{0.05}$	**District**	0.14	
	Seed sources within district	0.20	

Table1f showed that the leaf length was recorded maximum (5.30 cm) in district Mandi which was statistically at par with Kullu district and is significantly different with rest of the districts, whereas minimum (3.93 cm) leaf length was recorded in Shimla district. Within districts among both the seed sources, maximum leaf length of (5.31 cm) was recorded in seed source 1 of district Mandi and minimum leaf length of (3.80 cm) was recorded in seed source 1 of Shimla district which is significantly different with rest of the seed sources within districts. Similar findings have been computed by Pratap (1997) and Bist *et al*. (2001). It shows the potential for individual tree selection for leaf petiole length.

Table1g: Mean variation of fruit weight (g) of *Punica granatum* L.among districts and within district

Seed Sources	Seed source 1	Seed source 2	Mean
Shimla	25.97	25.57	25.77
Sirmour	24.92	24.34	24.63
Solan	24.30	23.82	24.06
Kullu	24.74	26.69	25.72
Mandi	27.56	27.86	27.71
$CD_{0.05}$	**District**	1.86	
	Seed sources within district	2.64	

Table1g showed that the fruit weight was recorded maximum (27.71 g) in district Mandi which was significantly higher as compared to other districts, whereas minimum (24.06 g) fruit weight was recorded in Solan district which was found to be significantly lower than Mandi and was found to be statistically at par with rest of the districts. Within districts among both the seed sources, maximum fruit weight of (27.86 g) was recorded in seed source 2 of district Mandi and minimum fruit weight of (23.82 g) was recorded in seed source 2 of Solan district.

Table1h: Mean variation of leaf petiole (cm) of *Punica granatum* L. among districts and within district

Seed sources	Seed source 1	Seed source 2	Mean
Shimla	0.37	0.40	0.39
Sirmour	0.46	0.47	0.46
Solan	0.48	0.48	0.48
Kullu	0.46	0.46	0.46
Mandi	0.47	0.48	0.47
$CD_{0.05}$	**District**	0.01	

Seed sources within district 0.02

Table1h showed that the leaf petiole was recorded maximum (0.48 cm) in district Sirmour which was significantly different with rest of the districts, whereas minimum (0.39 cm) leaf petiole was recorded in Shimla. Within districts among both the seed sources maximum leaf petiole of (0.48 cm) was recorded in seed source 1 and 2 of district Sirmour along with seed source 2 of Mandi district and minimum leaf petiole of (0.37 cm) was recorded in seed source 1 of Shimla district which was significantly lower as compared to rest of the seed sources within districts.

The parallel results to these finding was given by Wani *et al*. (2012). They computed leaf area of wild pomegranate genotypes ranged between 4.48 cm^2 to 14.04 cm^2.

Table1i: Mean variation of collar diameter (mm) of *Punica granatum* L. among districts and within district

Seed sources	**Seed source 1**	**Seed source 2**	**Mean**
Shimla	1.75	1.77	1.76
Sirmour	1.79	1.80	1.79
Solan	1.83	1.85	1.84
Kullu	2.17	1.85	2.33
Mandi	2.80	2.48	2.94
$CD_{0.05}$	**District**	0.04	
	Seed sources within district	0.06	

Table1i showed that the collar diameter was recorded maximum (2.94 mm) in district Mandi which was significantly different from rest of the districts, whereas minimum (1.76 mm) collar diameter was recorded in Shimla district which was statistically at par with Sirmour district. Within districts among both the seed sources maximum collar diameter of (2.80 mm) was recorded in seed source 1 of district Mandi and minimum collar diameter of (1.75 mm) was recorded in seed source 1 of Shimla district which was significantly lower to other seed sources within districts.

Table1j: Mean variation of Internodal length (cm) of *Punica granatum* L.among districts and within district

Seed sources	Seed source 1	Seed source 2	Mean
Shimla	3.34	3.35	3.35
Sirmour	3.34	3.33	3.34
Solan	3.37	3.38	3.38
Kullu	3.48	3.59	3.53
Mandi	3.69	3.78	3.74
$CD_{0.05}$	**District**	0.03	
	Seed sources within district	0.04	

Table1j showed that the internodal length was recorded maximum (3.74 cm) in district Mandi which was significantly higher than rest of the districts, whereas minimum (3.34 cm) internodal length was recorded in Sirmour district which was statistically at par with Shimla district. Within districts among both the seed sources, maximum internodal length of (3.78 cm) was recorded in seed source 2 of district Mandi and minimum internodal length of (3.33 cm) was recorded in seed source 2 of Sirmour district.

Table1k: Mean variation of number of branches of *Punica granatum* L. among districts and within district

Seed sources	Seed source 1	Seed source 2	Mean
Shimla	6.36	6.28	6.27
Sirmour	6.34	6.37	6.36
Solan	6.34	6.35	6.35

Kullu	7.11	7.62	7.36
Mandi	8.41	9.24	8.82
$CD_{0.05}$	**District**	0.16	
	Seed sources within district	0.23	

Table1k showed that thenumber of branches was recorded maximum (8.82) in district Mandi which is significantly different within rest of the districts, whereas minimum (6.27) number of branches was recorded in Shimla which was statistically at par with Solan and Sirmour district. Within districts among both the seed sources maximum number of branches (9.24) was recorded in seed source 2 of district Mandi and minimum number of branches of (6.28) was recorded in seed source 2 of Shimla district which is significantly different with rest of the seed sources within districts

2.) Cluster Analysis: Based onthe performance of various characteristics, the clustering pattern of different seed sources of *Punica granatum* has been presented in Table2.

Table 2: Clustering membership among districts and within districts of *Punica granatum*

Cluster	No. of Seed sources	Seed source
I	3	Narag,Neripul, Sadhupul
II	4	Rewalsar, Sundernagar, Sunni, Mohal
III	3	Waknaghat,Basantpur, Banjar

All the seed sources were grouped into 3 clusters. Maximum (4) number of seed sources i.eRewalsar, Sundernagar, Sunni, and Mohal were accommodated in cluster II followed by three seed sources in cluster I and cluster III respectively.

Table2: Clustering membership.

Cluster means for different characters to assess the considerable amount of variation which shows the existence of diversity among seed sources. The cluster means of various characters are presented in Table 2The maximum height was recorded in cluster II (6.95 m) and minimum height was recorded in cluster III (6.51 m). Maximum diameter was recorded in cluster I (13.12 cm) and the minimum diameter was observed in cluster II (11.91 cm). Maximum crown spread E-W was recorded in cluster I (4.62 m) and minimum crown spread E-W was observed in cluster II (4.24 m). Maximum crown spread N-S was recorded in cluster I (6.47 m) and minimum crown spread N-S was observed in cluster II (6.06 m). Maximum fruit weight was observed in cluster II (26.43 g) and the minimum was observed in cluster I (24.36 g). Maximum leaf length was recorded in cluster II (5.07 cm) and minimum leaf length was observed in cluster III (4.57 cm). The maximum internodal length was recorded in cluster II (3.57 cm) and minimum internodal length was observed in cluster I (3.35 cm) .The maximum collar diameter was recorded in cluster II (2.30 mm) and the minimum collar diameter was observed in cluster I (1.81 mm). A maximum number of branches was recorded in cluster II (7.76) and a minimum number of branches was observed in cluster I (6.35). Maximum leaf petiole was recorded in cluster I (0.47 cm) and minimum leaf petiole were observed in cluster III (0.43 cm).

Table3: Cluster means.

Characters	**Cluster**		
	I	**II**	**III**
Tree height (m)	6.73	**6.95**	6.51
Tree diameter (cm)	**13.12**	11.91	12.06
Crown spread E-W (m)	**4.62**	4.24	4.37
Crown spread N-S (m)	**6.47**	6.06	6.20
Fruit weight (g)	24.36	**26.43**	25.65
Leaf length (cm)	4.58	**5.07**	4.57
Internodal length (cm)	3.35	**3.57**	3.43
Collar diameter (mm)	1.81	**2.30**	1.82

Number of branches	6.35	**7.76**	6.77
Leaf petiole (cm)	**0.47**	0.45	0.43

Average inter-cluster distance values are presented in Table4. The inter-cluster distance D^2 value was highest between cluster I and cluster II (18.73) and the lowest inter-cluster distance D^2 value was observed in cluster II and cluster III (8.98). This indicates that seed sources included in clusters I and II have wide genetic diversity and could be used in a hybridization programme aimed at direct selection for characters or improvement of seed sources. Characters like tree height, tree diameter, and crown spread had more contribution towards genetic divergence, hence these characters are major determinants of genetic diversity in the present set of seed sources.

Table4: Average inter-cluster distance (D^2)

Clusters	**I**	**II**	**III**
I		18.73	10.18
II	18.73		8.98
III	10.18	8.98	

3) PRINCIPAL COMPONENT ANALYSIS

To interpret the data in a more meaningful form, it is necessary to reduce the number of variables to a few interpretable linear combinations of variables. Thus, principal component analysis was employed to reduce the observed variables into a number of principal components that will account for most of the variation in observed variables.

The result about principal component analysis has been presented in Table5. Table6revealed that three of ten principal components (PC_S) had eigen values greater than unity and therefore these three principal components are playing the main role in the analysis. Thus first three principal components had been retained in the analysis, which explained 69.263 per cent of the total variation.

The first principal component had eigen value 3.468 and it explained 34.675 per cent of the total variation. The second principal component had eigen value 2.300 and explained 23.002 per cent of the total variation. The third principal component had eigen value 1.159 and explained 11.587 per- cent of the total variation.

Table 5: Eigen vectors of principal component analysis

Variables	**PC_1**	**PC_2**	**PC_3**
Tree height (X_1)	**0.674**	0.639	-0.079
Tree diameter (X_2)	0.520	**0.662**	-0.033
Crown spread E-W (X_3)	0.513	**0.629**	0.389
Crown spread N-S (X_4)	**0.418**	0.228	-0.327
Fruit weight (X_5)	-0.107	0.336	**0.750**
Leaf length (X_6)	-0.195	**0.374**	-0.353
Internodal length (X_7)	**0.847**	-0.441	0.089
Collar diameter (X_8)	**0.851**	-0.475	0.108
Number of branches (X_9)	**0.812**	-0.509	0.029
Leaf petiole (X_{10})	**0.394**	0.272	-0.330
Eigen values	3.468	2.300	1.159
% of variance	34.675	23.002	11.587
Cumulative % of variance	34.675	57.677	69.263

The first principal component was linear combination of tree height, crown spread N-S, inter-nodal length, collar diameter, number of branches and leaf petiole. This component may be interpreted as stem growth. The second principal component was linear combination of tree diameter, crown spread E-W and leaf length which represent tree characteristics. The third principal component comprised of only fruit weight which represent fruit characteristics.

4) DISCRIMINANT ANALYSIS: The approach of categorizing high and low yielder seed sources on the basis of randomly selected characteristics is statistically weak. The discriminant analysis is a systematic and statistically valid procedure for this purpose. In the present study, the seed sources were first divided into two groups namely 'high yielder' and 'low yielder' on the basis of average value of fruit weight and discriminant function was fitted. The discriminant function was found to be:

D = -41.41 -1.68 X_1 + 0.37X_2 - 1.67 X_3

Where D stands for fruit weight, X_1 for tree height, X_2 for tree diameter and X_3 for crown spread E-W. Thus, this equation reveals that the characters tree height, tree diameter and crown spread E-W are the most important characters to develop discriminate rule which discriminate the two groups. The value of Wilk's lambda (λ) was obtained to be 0.140 and which in turn, gave the computed value of chi square (χ^2) as 7.862. The seed sources were assigned to group 1 (High yielder) if D $\geq$ m otherwise to group 2 (low yielder), where m = 0.45 is the average of group centroids. The groups formed on the basis of allocation rule are given in Table5. Six seed sources were classified as high yielder, whereas four seed sources were low yielder. The seed source Rewalsar and Sundernagar from Mandi district, Mohal and Banjar from Kullu district and Basantpur and Sunni from Shimla district were categorized into high yielder seed sources.

Table6: High and Low yielder seed sources

High yielder Seed Sources	**Low Yielder Seed Sources**
Rewalsar	Narag
Sundernagar	Neripul
Mohal	Waknaghat
Banjar	Sadhupul
Basantpur	
Sunni	

Thus Shimla, Mandi and Kullu districts was found to be high yielder, whereas Solan and Sirmour districts were found to be low yielder seed sources.

Summary and Conclusion: On the basis of this study, following conclusions were drawn:

Fruit weight, leaf length, internodal length, collar diameter and number of branches per plant were found maximum in Mandi district. All Seed sources were grouped into 3 clusters and maximum inter cluster distance was between cluster I and II. Tree diameter (cm), tree height (m) and crown spread (m) were the most important characters to discriminate different seed sources into high and low yielder groups. Seed sources Rewalsar and Sundernagar from Mandi district, Mohal and Banjar from Kullu district and Basantpur and Sunni from Shimla district were categorized into high yielder seed sources. Three principal components (PC_S) were extracted out of ten which explained 34.675, 23.002, and 11.587 per cent of the total variation respectively amounting to 69.26 per cent of total variation.

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